Cause.—The fact that brilliant shifting auroras are accompanied by magnetic storms renders it practically certain that they, and presumably therefore all auroras, are due to electric discharges; and the further fact that they vary in frequency with the sunspot period indicates that this current either comes from or is induced by the sun. For some time it was thought probable that auroras are caused by negative particles shot off from the sun and entrapped by the magnetic field of the earth. On the other hand, Vegard [4] has given strong arguments in favor of the α particle which is positively charged, and Störmer [5] has found at least one case that required the positive charge to account for the observed magnetic disturbance.

The evidence, then, while not conclusive, indicates that auroras are due to streams of α particles in the upper atmosphere shot off by radioactive substances in the sun.*

the sun. We may assume that at such times great jets or streams of electrified matter (electrons perhaps), akin to cathode rays in a vacuum, are projected with high velocities outward, and that occasionolly some of these jets cross the earth's orbit or pass near to it, being when leaving the sun in a general radial direction, bent backward, for obvious reasons.

That electrified matter in a vacuum does move in jets or streams for indefinite distances is a fundamental fact. Moving charges of the same name in paths, straight or curved, act like parallel currents and attract one another, the more as their velocity is greater, until the static repulsion of such like charges sets a limit to further approach. It is possible that the space around the sun may be crossed by many such jets or streams of electrified matter moving at very high velocities into the vacuous space. The coronal streamers may be the visible composite effects of the projected jets. Such electrified jets may act

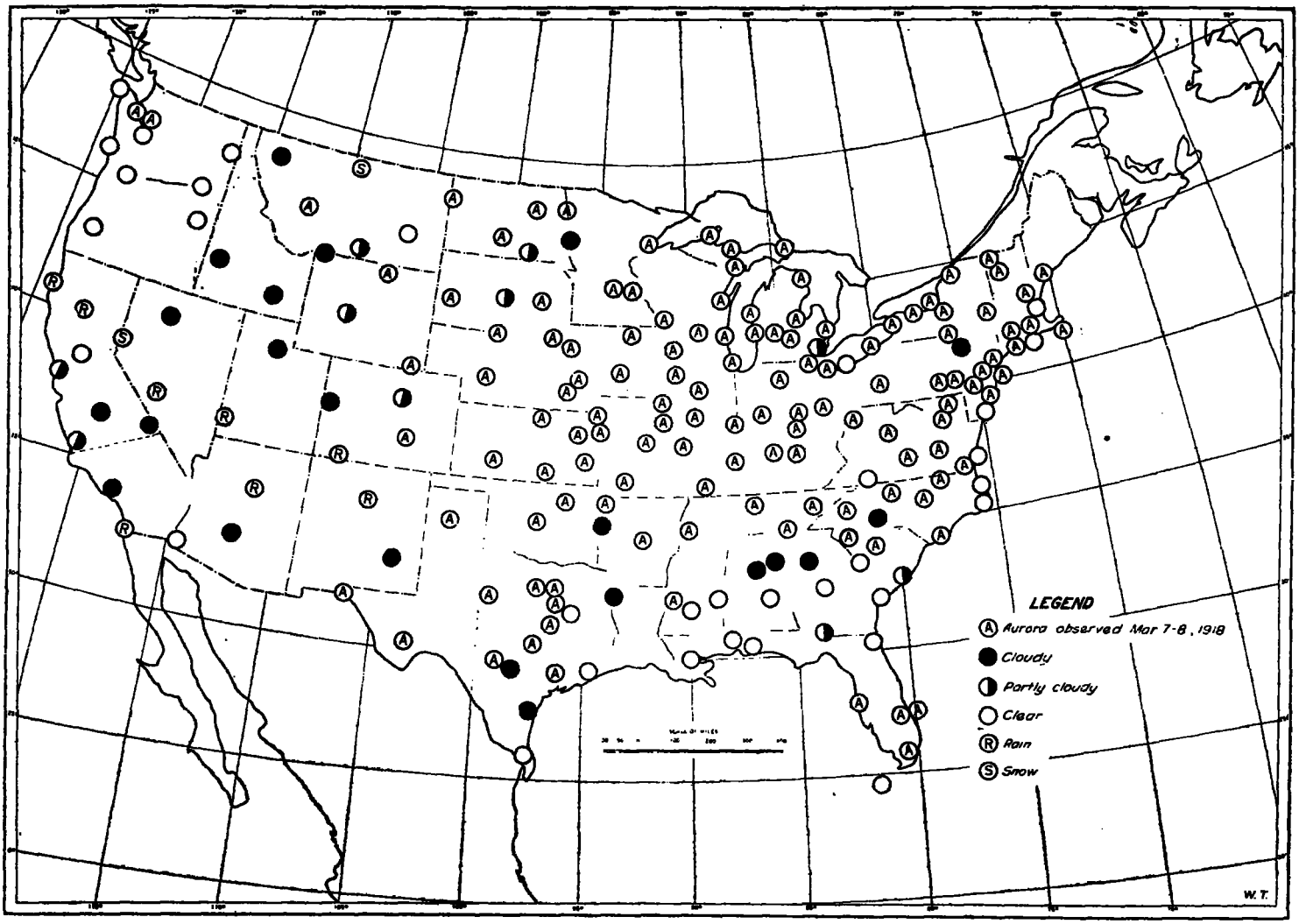

FIG. 1.—Where the aurora of Mar. 7-8, 1918, was observed.

INFERENCES CONCERNING AURORAS.

CERTAIN PHYSICAL FACTS REGARDING THEM.[6]

By ELIHU THOMSON.

It seems doubtful if any extensive auroral display has occurred without coincident existence of exceptional areas of disturbance on

inductively by proximity to the earth or directly by conduction of electricity to the earth's outer atmosphere.

In the present paper, however, it is hoped to prepare the way for further study by pointing out certain physical facts regarding the relations of auroral phenomena to the earth and its atmosphere; to locate and give direction to the streamers seen in auroras; and to explain the nature of the so-called auroral arch, the zenith crown, and other characteristics. It is believed that the following propositions may be shown to be true:

1. Streamers seen in auroras, singly or in composite masses, are in reality vertical, or approximately so, to the earth's surface, nearly parallel when adjacent, and only slightly divergent even when miles apart; the divergence being due to curvature of the earth's suriace.

2. In many auroras, the streamers appear to be located in bands or zones more or less wide in latitude, extending generally in east-and-west direction, or forming belts or zones between parallels of latitude in which the streamers extend vertically upward like trees in a forest. * * * The same auroral appearances are possible to be seen alike at different places simultaneously only when a system of vertical streamers exists. * * *

[4] Phil. Mag., 1912, 23:211.

[5] Terr. Magnet. and Atmos. Elec., 1915, 20:1. See also, 1917, 22:23 and 97 (abstr. Sci. Am. Supp., Mar. 30, 1918, p. 197).

* For a good, well-illustrated, popular account of the theory of the aurora, see Sci. Am. Supp., Aug. 31, 1918, pp. 132-134.

A very complete bibliographical, mathematical discussion: "Bericht uber die neueren Untersuchungen am Nordlicht," by L. Vegard seems to be the best aurora paper now in print: Jahrbuch der Radioaktivität und Elektronik, 1917, 14:383-465, 7 figs., 5 tables. The bibliography, pp. 385-387, contains 86 titles. The titles of the five chapters are: I, "The most important characteristics of the aurora"; II, "Historical summary of the theory of the aurora"; III, "Establishment and foundation of the cosmical ray hypothesis and theory of the aurora"; IV, "The characteristics of the aurora in the light of the cosmical ray theory"; and V, "The physical nature of the cosmical rays."

[6] Quoted from Proc. Nat. Acad. Sci., Washington. (Reprinted in Sci. Am. Supp. 2151, Mar. 24, 1917, pp. 182-183.)

3. In some rare auroras the vertical streamers are closely limited to a narrow belt of latitude; sometimes only 2 or 3 degrees, or even less, in width north and south, while the east and west extent of the narrow belt may be very great.

4. In widespread auroras the belt of vertical streamers may cover great extents of latitude and extend east and west unlimited distances. This appears to have been the case in the recent great aurora of August 26, 1916.*

5. The curvature of the so-called auroral arch is an optical effect of perspective, slightly added to by the curvature of the earth. The appearance of folded curtains of streamers is a similar effect of superposition and perspective when the active band or zone covers many degrees in latitude. It is probable that the lower ends of auroral streamers have about the same height in the earth's atmosphere; a layer from which they stream upward to heights which vary in different displays or even in the same display. This layer probably exists at a height of about 50 miles and conducts laterally or horizontally, thus distributing the electricity discharged from it into the streamers.

6. The convergence of long streamers toward the zenith seen in the greater auroras is purely an optical effect of perspective, the streamers being vertical.

7. The so-called zenith crown is in reality due to bundles of streamers, nearly vertical but seen on end. They appear as patches of shifting light in or near the zenith, sometimes surrounded by apparently converging streamers from the north, east, and west, and even from the south; converging in appearance only.

8. The convergence of streamers is of the same nature as the convergence of straight parallel railway tracks in the distance, or better, the apparent convergence toward the sun of the sunbeams seen in dust-laden air, when the sun itself is obscured by a small irregular cloud, or is back of a broken mass of clouds. * * *

It can readily be seen that the recognition of the vertical relation of streamers to the earth's surface and the nearly constant level of their lower ends simplifies to a great extent the study of auroras, particularly the determination of the total height reached by them, curvature of the earth being allowed for. The effect of this curvature will be less the higher in altitude the auroral arch, or the nearer it is to being overhead. The streamers are often observed to rise from the arch first as short streamers, gradually developing and extending upward until their upper ends are a few degrees from the zenith. When they originate in an arch which is of low altitude and extend nearly to the zenith, as they appear to do in the greater displays, their length must be hundreds of miles, possibly in some instances reaching one thousand or more. It would appear that no limit can be set for their possible height. In most auroras, however, the visible extent of the streamers is more limited. A low-altitude auroral arch implies great distance north from the observer and for a given actual streamer length a less apparent height or length. Paulsen's class of auroras without streamers may mean either that the streamers are too short and too many to be noted separately, or that the electrification is too feeble for their development, the observed luminous glow being due to flow of current in the conducting layer itself, an arch forming horizontally, but without outward projection.

If our assumptions are approximately correct the arch of an aurora, if located farther north than about 600 miles from an observer, will be below his horizon, but the streamers extending upward from it if long enough may be seen. Auroras far north of this will probably be invisible or be seen merely as a luminous glow well down on the northern horizon. When the breadth in latitude of the auroral zone is great and the display is seen from the south, the streamers may overlap or be arranged in apparent curtains or folds, the lower ends of the streamers being in that case at varying apparent altitudes above the northern horizon even when in the same general line of view. In such case they may be superposed in the line of sight and therefore be composite, or increased in apparent length owing to imperfect superposition in their lengths with respect to those back or front of them. It is believed that these and like considerations will suffice for the explanation of observed appearances of auroras in spite of their great variety.

PRINCIPAL FEATURES OF THE AURORA OF MARCH 7–8, 1918.

Time of occurrence.—Since the aurora is generally considered to be the result of the arrival of clouds of particles, or special "rays," from the sun, important variations in brilliance should be noted almost simultaneously over the whole earth wherever the display is seen. This brilliant March aurora attracted much attention because it coincided with an air raid upon London. "The northern sky was lighted up with a crimson glow both before and during the raid, which started shortly after 11 p. m.[7]

A magnetic storm of no great duration, but very considerable amplitude, was recorded at the Eskdalemuir, Kew, and Agincourt (Ontario) Observatories on the night of March 7–8, 1918. It began with 'a sudden commencement' at about 9h. 10m. p. m., on March 7. The largest movements occurred in the early morning of March 8, between 1 and 5 a. m., but smaller oscillations persisted for some time after the latter hour.

In the United States the earliest auroral observation reported was 0h. the 8th, G. M. T., the display appearing at twilight at a number of places. The maximum phase, that is, the greatest brilliance of the aurora was reached generally between 3h. 30m. and 3h. 40m. a. m. (G. M. T.); for hours, however, the display was exceptional. The end of the aurora occurred generally between 4h. 30m. and 5h. a. m. (G. M. T.), though a revival was seen at some sations between 7 and 8 a. m. (G. M. T). It is evident that the aurora was coincident with the major features of the accompanying magnetic storm.[8] Since the greatest magnetic disturbances occurred between 1 and 5 a. m. (G. M. T.) (7 to 11 p. m., 90th meridian time), observers in North America were the most likely to see the aurora.

"It is possible that the disturbance was a repetition after three 27-day intervals of the large magnetic storm of December 16–17, 1917. There was a very considerable disturbance on January 12 at the end of the first 27-day interval and a minor disturbance at the end of the intermediate interval in February."[7] The brilliant, partly crimson aurora observed April 5 (with lesser ones April 4 and 6, in New Haven, Conn., and elsewhere) seems to have marked the last, intense, periodic recurrence. Since the synodic rotation period of the sun is about 27 days, it seems that on five successive presentations of a particularly active area on the sun, the earth received an unusual quantity of magnetically disturbing emanations.

General appearance.—While there is a general unanimity concerning the time, colors, and brilliance of this aurora among widely scattered observers, there is an almost endless amount of differing detail in the descriptions of the appearance, brilliance, movements, and changes in the positions of important factors of the display. In the nature of the case, since the clouds of electrons arriving from the sun could not be homogeneous the aurora must be streaky or spotted in character. This may account for the inexact synchronism of the times of brighter display, particularly the maximum phase, between 9:30 and 10 p. m. (90th meridian time). How a given bright portion will look must depend largely on the location of the observer. Since the altitude of the aurora is generally more than 90 km., particular features of display should be visible at the same time from widely separated localities.* The actual location of the aurora is thus the limiting factor in the distance to which it can be seen: and the clearness of the air determines its visibility within the possible limits.

* See MO. WEA. REV., 1916, 44:440-444; also Science, N. Y., 1916, N. S. 44:717-722; and Sci. Abs., 1917, 573.

[7] Quotations from Nature, Mar. 14, 1918, p. 32. (Repr. in Science, Apr. 12, 1918, p. 359.)

[8] The closeness of the interrelation between this aurora and the magnetic storm is well brought out by a comparison of the descriptions that follow, with Dr. D. Chree's article, "Magnetic Storm, of March 7-8 and August 15-16, 1918, and their discussion," Proc. Roy. Soc., Ser. A, vol. 96, pp. 32-55, Aug. 1, 1919.

* Cf. E. Loomis: A Treatise on Meteorology, N. Y., 1899 edition, pp. 173-201. This is a very complete illustrated description of the aurora.

See also Cl. Abbe's articles, "Altitude of the aurora above the earth's surface;" Terr. Mag., 1898, 3: 5-12, 53-76, 149-178